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THE STRATEGICS OF SCIENTIFIC INVESTIGATION

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The thirty spokes unite in one nave; but it is upon the space for the axle that the use of the wheel depends.—Lão-Tsze.

IN all ages and among all races since man first made his début upon our earthly stage, certain individuals have differed from their fellows in the possession in unusual measure of impersonal curiosity combined with powers of observation, comparison and generalization. Where historic record fails we can infer the existence of these individuals from the heritage of knowledge which they conferred upon their descendants. Such knowledge did not come to man by revelation, or rather, let us say, the revelations of past ages did not differ in kind from those of our own time. The mental exertions which led to the development of the stone axe from the fortuitously encountered sharp fragment of flint did not differ in kind, possibly not even in degree, from those which led to the development of the aeroplane from a Chinese toy.

These individuals, whom I prefer to call investigators, avoiding alike the barbarism of the word "researcher" and the restricted connotations of the word "scientist," have but rarely, at any stage of the world's history, appeared of any importance in the eyes of the acknowledged rulers and leaders of mankind. In so far as they have occasionally combined charlatanry with science, as in the case of the ancient or medieval astrologers or a certain type of modern inventor, they have, it is true, occasionally achieved notoriety and the consequence attaching to the recipients of the beneficent toleration of rulers. In times of actual and impending disaster the desperate ruler not infrequently turned to his men of contemplation, to his astrologer, his magi or to Archimedes, with the helpless confidence with which the stricken patient turns to the surgeon upon whose labors he has never bestowed a thought in his days of health. History repeats itself, because the politicians and financiers of to-day are merely protean forms of the satraps and merchants of Persia, or the senators and bankers of old Rome placed in a different material setting, and the parallel between the European governments of to-day turning desperately to science for aid in the extremity of their peril and the Oriental emperor who in a like pass appealed to his wise men who were versed in the stars, would be comic indeed, were it not so unutterably tragic.

It has been but rarely, and then wholly fortuitously, that the investigator has been valued as a potent factor in society. In those rare instances it has been the individual who was valued, not the type, and the value has generally been that which the collector places upon a unique item in his collection, or which the vaudeville artist places upon his performing panther, or that vague and fruitless veneration with which the sage, the hermit or the dear old impractical sweetly-disposed rector of an English village is not unfrequently regarded—veneration which arouses no desire of emulation, but which finds its source in the incomprehensibility of the inspiring motive or its remoteness from the commonplace.

It has not infrequently been recognized by rulers that the patronage of learning has occasionally been rewarded by unexpected benefits, and from Hiero relying upon Archimedes for the defence of Syracuse to Christina of Sweden summoning Descartes to read to her before breakfast, rulers have sporadically contributed to the service of investigation. In modern times likewise it is officially recognized that the investigator may be an ornament to the state, but, save in the times of stress aforesaid, no hint of consciousness is betrayed that the labors of the investigator may constitute the very framework of civilization.

"Old women for old women," says Walpole, referring to the Royal Society, "I would trust to the analysis of the matrons in preference to that of the philosophers."¹ When the master-investigator of all time, Michael Faraday, ventured, in response to the ill-advised persuasion of his friends, to apply to government for a minute fraction of the recognition to which his incalculable services had entitled him, he was received by Lord Melbourne with the epithet "humbug." In 1914 when one of the greatest medical investigators of our day preferred a similar request to government his plea was received by the official overlords with the silent contempt of utter indifference.²

The mental attitude of the general public towards the investigator is similar to, but less financially profitable than, the attitude of tolerant and half-contemptuous admiration which is displayed towards the artist and the virtuoso, and it would be alike endurable were it not fraught with the very gravest dangers. What confidence would we possess in the lawyer unaware of the sources of common law or in the doctor who was professedly ignorant of the anatomy and physiology of the human body? What confidence shall we then display in the statesmen who remain oblivious and blind to the nature of the formative forces which under their very eyes are continually refashioning civilization? A momentary recognition of the danger of ignoring the investigator is,

¹ "An Account of the Giants Lately Discovered," 1766; Works of Horatio Walpole, 1798, Vol. 2.

² Cf. correspondence in the *Morning Post* and other London newspapers in the spring of 1914.

it is true, being displayed throughout the civilized world at present, owing to the crucial part which his labors play in the organized destruction of life and property which is the chief preoccupation of civilized peoples at this date. Good resolutions are being actively formed in Great Britain, America, Canada and Australia, resolutions which find expression in governmental plans for the future administration of scientific research. The education and training of the professional politician is, however, so purely legal, commercial and, in rare instances, literary, that it is not a matter for surprise that the various schemes for the furtherance of research which have thus amiably been put forward betray little comprehension of the real needs and potentialities of the investigator and little or no grasp of his true significance in world politics. Indeed the various plans which have been proposed will, if they materialize, carry with them very real dangers to true research and were the investigator as stridently vocal as the politician, I think it not unlikely that in many quarters at the present juncture earnest appeals might be heard from the scientific investigator to be saved from his friends and to be favored once more with the obscurity to which, like certain fish which dwell in caves, he has become by habitude adapted.

The various plans to which I have made allusion all bear indeed the unmistakable stamp of the mental bias of the political administrator. They unite in assuming that any given problem can be solved provided only the requisite number of persons, duly provided with diplomas, be paid to investigate it under the supervision of course of the omniscient administrator, who, in some of the plans I have instanced, is not even required himself to take part in the labors of his employees. Such tactics are well known to succeed in the production of public buildings, and while it may well be doubted whether they ever produced a Milan Cathedral, still they have given rise to many imposing edifices and why not, therefore, to the halls and corridors of science?

And then, of course, all of these plans unite in assuming that the public investment in science must be made to "pay." Now the author is far from taking the view of certain of his scientific colleagues that any association of commercial value with the products of research is inevitably accompanied by a degradation of ideals. The ultimate object of investigation lies in the attainment of complete control and understanding of our environment and only in so far as our environment is subject to control does it become of value to us. The whole difference between the value of our world to-day and that of the world inhabited by neolithic man is, as I have sought to show in a previous article, the product of the labors of the investigator. But these labors, however inchoate and devoid of the inspiration of a broad predetermined policy, have nevertheless in the past been for the greater part the result of an enlightened and penetrating curiosity and have not as

a rule been dictated by a sense of immediate or personal advantage. They have therefore resulted in the attacking of broad problems, for the nonce unprofitable but in their fruition how deeply fraught with significance to humanity! If the kind intentions of our political friends are executed, however, all this will now be changed, the old academic notion of the remoteness of the investigator from the everyday exigencies of life will be swept away, the unpractical investigation of the laws of atomic affinity will be replaced by an intensive study of cheese-making and the inspiring contemplation of the mysterious structure of the crystal will be replaced by a study of improved methods of hardening steel.

I am far from attempting to impugn the value or the ultimate as well as proximate importance of these studies of immediate practical concern. The Infinite lies hidden in every grain of sand and no object whatever is devoid of dignity as an object of research. Pasteur was led to his epoch-making investigations which have ameliorated so much of human pain and suffering by a study of the problems encountered in the manufacture of wine and of silk. Faraday's genius for research found the path to a new world through his attempts to provide manufacturers of optical instruments with a new and more satisfactory type of glass. But the doubt which assails me is this: Supposing our political friends had by happy chance engaged a potential Faraday or Pasteur to investigate the chemistry of cheese or the hardening of steel and suppose in the course of these utilitarian investigations he too were to tap a vein of knowledge leading deep into the heart of the mysteries of our environment, would he be permitted so unprofitable a divergence from the main object for which he had been hired? However sympathetically inclined his immediate overseer might feel, I think that it might be difficult to convey to the politicians to whom he in turn would be answerable the ultimate significance of such abstract and generalized investigations, and when in turn the matter came to be referred to voters, *i. e.*, taxpayers, I fear it would go hard with our new Faraday or Pasteur.

The wind bloweth where it listeth and the spirit of man can not be confined within premeditated bounds. This human institution, the institution of investigation, must like other human institutions be of natural and spontaneous growth or it will inevitably decay. Just as a church can not be established by statute, nor a system of law be perfected in the brief deliberations of a committee, so scientific investigation must develop of itself, by the expression of its own internal vigor, into an autonomous and self-supporting institution, integrally welded into our daily lives and the living expression of a need and a function of society.

Such, indeed, in slow and painful stages has been the past devel-

opment of science and such, in an accelerated measure, must be its development in the future. There is, indeed, a legitimate sphere for governmental enterprise in that gap between pure science and practical industry which has hitherto been so imperfectly bridged. But the activity of governments in this field can not stimulate the broader activities of the investigator and there is, on the contrary, ground for serious apprehension that the activities of governments in this direction may actually result in depriving the broader and ultimately more significant investigations of the means for their prosecution. The government institutes for research having been founded and munificently endowed, why should further grants and endowments be furnished for investigations which are not carried out under government control? The danger is that cheese-making and steel-making and the like being adequately provided with expert scientific advice the politician may decide that all is now well with the investigator and turn with relief to the more familiar problems of "practical politics."

In order to combat this tendency and to stimulate the spontaneous development of investigation in a measure commensurate with the accelerated velocity of modern social evolution, it is a vital necessity that investigators the world over should at this time take thought and counsel among themselves as to the new ways and means to be adopted, the secular changes in our procedure which will bring our institution of investigation more closely into harmony with the increasing complexity of modern development. Just as, from time to time in the world's history, when some crisis has brought into prominence the misfit between existing institutions and actual needs, the churches have changed and adapted their organization and the existing body of laws and legal procedure have been subjected to reform, so in this day of crisis our institution of investigation must be subject to a like scrutiny and the origin of misfit between existing need and existing procedure sought and if possible removed.

In past centuries the investigator has been largely content to rely for the satisfaction of his personal needs and those of his profession upon the largesse of patrons. So far this procedure has yielded results the vast import of which it would be impossible to exaggerate, and is unquestionably destined still, perhaps for many generations, to provide the main support of this service of mankind, but as the exclusive means of subsidizing investigation it is outworn and ill-adapted to the needs of our present time. To-day we see that increasing patronage, so far from constituting fresh opportunities for science, actually constitutes a grave danger to the welfare of the broader and more fundamentally important types of investigation. The channels are to be made deep for the ultimate trickles, but the fountain-head from which the waters of knowledge proceed is to be neglected, possibly in even greater meas-

ure than in the past, and we may well apprehend that in course of time it may become clogged to the serious impairment of its outflow. The remedy lies in our hands and individually or collectively the decision must be taken now. There is only one solution of our problem and that is to cast off our swaddling bands, cut ourselves loose from patronage, and take into our own hands the destinies of our own institution. While enlightened private patronage will still in a measure contribute towards the achievements of investigation in the future, in ever-increasing degree we must cease to be dependent upon others and look to the product of our own efforts to afford us the material foundation of fresh enterprises. I have elsewhere endeavored³ to form some imperfect estimate of the monetary equivalent of the colossal value to which the accumulated investigations of mankind have given rise. Where values are so enormous, comprising almost the entire value of existence, such estimates are necessarily only fragmentarily valid. One fact is abundantly demonstrated, however, and that is that by far the greater part of the summated value of the manufacturing industries of our day owes its existence to and depends for its continuance upon the labors of the scientific investigator. Of the vast annual income which is realized by these manufactures and which arises out of their patents a barely discernible fraction ever finds its way back to furnish the means of providing fresh discoveries and fertilizing the field upon which we must rely for the production of fresh growths of industrial enterprise.

If the scientific investigators produce this vast wealth they can also in some measure control its disposal and by observing the guiding principle that in a steadily increasing degree investigation must be made self-supporting, they will undoubtedly in time be enabled to deflect some proportion of this wealth, and a very small proportion indeed would be sufficient, to the services of their institution.

In isolated and strikingly successful instances this principle has already been practically applied. The Solvay Institute in Brussels owes its existence to the wealth proceeding from the discoveries of Solvay. The Institute of Experimental Therapy in Frankfort to which medicine already owes practical results of stupendous significance is supported by the proceeds accruing from Ehrlich's patents and the Research Corporation in New York, deriving its income from the Cottrell patents, is the first instance of a more fundamental and far-reaching endeavor to place the institution of investigation upon a self-supporting basis. It is through repeated independent applications of this principle that the extensions and proliferations of research in future generations are to derive their material bases.

The objection will unquestionably be urged by many scientific pur-

³ "The Cash Value of Scientific Research," *THE SCIENTIFIC MONTHLY*, 1 (1915), p. 140.

ists that this procedure would involve the "taint" of commercialism, that once the investigator enters into the market-place his ideals will be contaminated and the purity of his aims sullied. My reply to this is that a fundamental instinct of mankind can not be suppressed so easily. Investigation will proceed even if individual investigators fall by the wayside, and the distinguished instances of successful enterprise of this type to which I have drawn attention are living proofs that the investigators to whom they owe their origin were not so lacking in determination and enthusiasm as to relinquish their life-work merely because personal advantage tempted or the chaffering of the market disturbed them.

Churchmen in all ages have been known to sacrifice personal advantage to impersonal ideals, statesmen have occasionally placed patriotism before profit. Are investigators then so inferior to other men, of so delicate a moral and mental fiber that they will be ready to sacrifice their ideals at the altar of Mammon directly the opportunity presents itself? Or is it, that never having submitted to the trial they are needlessly distrustful of their own moral stamina? I doubt not that the objector would, if questioned, be confident of his own ability to hold fast his ideals, it would be the weaker brother for whom he would be solicitous. Well, let the weaker brethren go, for we can readily spare them, and they too may have their utility in the "debatable land" between science and industry to which I have alluded as a future sphere of governmental or commercial enterprise.

Should the few but noteworthy precedents which have already been set develop, as I am confident they will, into an avowed policy of the majority of scientific men, then a momentous thing will have happened, for science will have capital of its own to dispose of without fear or favor, without deference to the caprice of the patron or the objectives of a donor or the utilities of the moment. When this hour arrives the campaign of the conquest of nature will have entered upon a new phase, and, equipped at last to conquer, a definite strategy of investigation will have become an imperative necessity.

Investigation has hitherto proceeded haphazard, a compromise between the availability of funds and the talents and inclination of the investigator. These latter must always remain a determining factor, but the availability of the paltry means which are usually needful will, it is to be hoped, cease to determine with iron and senseless rigidity the evolution of civilization. At the present time it is comparatively easy to obtain money to endow astronomy, because the subject is in itself inspiring and has never lacked great popularizers and expositors and also perhaps in some measure because a telescope or an observatory is a visible monument to the donor. It is easy to obtain money for objects of real or fancied utility, for the investigation of certain aspects

of medicine or agriculture. But it is difficult to obtain money for the investigation of recondite phenomena in physics or chemistry or for such subjects, for example, as the psychology of insects. Yet if perchance the strategist of investigation were to survey the whole field of scientific knowledge as one might survey a map he would inevitably find that all subjects of investigation are closely interwoven and mutually interdependent. Slowness of advance in one direction cripples advance in another, lack of knowledge in some at first sight unrelated field prohibits the fruition of research elsewhere.

Then, again, apparent value is not in the least identical with the real or ultimate value of investigation. To the man in the street it may appear that the study of fertilizers or of soils, of minerals or of dyes affords at the present time the fields of prime importance. Without in the least detracting from the proximate and ultimate value of such researches, the biochemist, looking a few decades farther ahead, can see in the study of the phenomena of fermentation, of enzyme action, the germ of a future discovery, the artificial photosynthesis of carbohydrates, which will accomplish nothing less than an industrial revolution and sweep aside at one stroke the economic problems of immemorial centuries. Yet with such a possibility lying dormant in the subject, where do we find an elaborately equipped institution for the scientific investigation of enzymes, where leading investigators in the field are congregated and all the resources of modern physics, chemistry and biochemistry backed by the necessary equipment are brought to bear upon this field, fraught with such vital significance to man? If there exists indeed such an institute then I am ignorant of its whereabouts and of the names of the members constituting its staff. The field is not one which has appealed to patrons, the word fermentation reveals to them only the manufacture of beer, which is not the most inspiring of our industries. But the strategist of investigation would place his finger upon this spot in the terrain of scientific conquest and order up reinforcements to support the thinly scattered and ill-equipped forces which at present represent the sum total of human endeavor to enter into possession of this new world which lies before us.

Another subject which will doubtless greatly interest the future Parliament of Science will be that of the geographical distribution of investigation. Here, too, our absolute dependence upon patronage has unfavorably influenced the development of our institution. At present an enormous proportion of organized investigation is being conducted in the vicinity of the large centers of population in Europe and North America. That is partly because of the natural tendency of investigators to congregate in the neighborhood of the patron who endows their labors, and partly owing to the fact that in the absence of any Parliament of Science or analogous deliberative body to discuss such

broad questions of policy, active investigators have arisen to notice in those localities where opportunities are most abundant, new opportunities have been created for them and thus, if this centripetal process is to continue unmodified by some centrifugal policy of distribution, the facilities for research will tend to become in ever-increasing degree confined to a comparatively small number of centers of population.

It is, of course, having regard only to the effects and achievements of investigation, totally immaterial where it may be conducted, but from other points of view the present centripetal tendency of investigation is a serious handicap to the accelerated development of this function of society which is imperatively demanded by the rapidly increasing complexity of our social and material environment. In the first place the congregation of investigators in a single center leads, through constant personal interchange of views, to a certain uniformity of thought which, not infrequently, becomes indistinguishable from prejudice. The scientist who has travelled can not fail to have observed that his colleagues in Berlin, for example, all share a certain number of views regarding the field in which they labor; his colleagues in London will have a somewhat different group of opinions in the foreground of their thoughts, while those in New York will esteem yet a third group of phenomena or hypotheses as of prime immediate importance. This is inevitable, because no investigator, no matter how virile and creative his intellect, can form an opinion from personal, unprejudiced experience on every phase of his chosen subject and he therefore in such matters provisionally absorbs any plausible opinion which lies nearest to hand. His acceptance of such opinions is provisional and subject to revision in the light of fact, it is true, but prior to or failing such revision it must play its proportionate part in determining his mode of investigation in other fields. Obviously a centrifugal distribution of investigation would reduce this tendency towards gelation of hypotheses to a minimum and produce among investigators as a whole that catholicity of outlook and variety of attack which is the condition of success in the interpretation of the myriad manifestations of the complexity of our environment.

But the present centripetal tendency is fraught with yet more serious consequences, for centralization of investigation implies centralization of the opportunities for investigation. At the present date in New York, London, Paris or Berlin the young man who has capability for original investigation has every opportunity of acquiring facilities for his work and for gaining inspiration from the example of investigations proceeding to a successful issue in his own vicinity and under his own observation. He sees in actual operation the methods of work adopted by masters of his subject, and example and opportunity alike combine to make the path easy to his chosen career. But what shall

we say of the opportunities of the young man in Siberia, China, Australasia, South America or Africa? We can not doubt, in some instances we have living proof, that the populations of these countries, granted equality of opportunity, would produce their proportionate quota of talented investigators. In certain localities in these countries every necessary institution exists for providing the essential preliminary training of the investigator, but, training in the fundamentals of his subject secured, where is he now to turn for the living example of the great investigator or for the opportunities of a laboratory partly or wholly devoted to research? The bare possibility of creating fresh fields of knowledge in his chosen territory will probably never even occur to him, since he has never seen or been stimulated to imagine investigation conducted on a broad and practical scale. Thus he turns his energies to other fields and perchance may dissipate on trifles talents which would have been of priceless value to civilization. As a means, then, of tapping new sources of talent for investigation, a centrifugal disposal of investigators and the opportunities for investigation has now become a paramount necessity.

But long ere we can accomplish a fraction of these desirable reforms and developments of our institution a new spirit must arise among investigators themselves. For centuries they have held themselves aloof from the world and centered their regard too exclusively upon their chosen special fields. Few indeed are the investigators of the present day who devote any proportion of their time to reflection upon the ultimate import of their profession, fewer still are conscious of a uniting purpose binding them to the investigators of all lands and times, of the historical continuity of their labors, or of the vital significance of their function in society. The communal spirit which arises from the awareness of common aims and the certitude of irreplaceable usefulness which is the driving force of any and every human institution is as yet, in our institution of investigation, but inadequately aroused. If we are to take our rightful place in the scheme of things and acquit ourselves as becomes our responsibility we can not too soon take these fundamental aspects of our profession seriously into consideration.

And above all let no investigator be ashamed of his profession and let none regard his labors cheaply, for the investigator is the pathfinder and the pioneer of new civilizations; he is more than that, he is the interpreter of the Infinite.